Chapter 2
Theoretical Background

2.1 Introduction

With respect to the literatures and previous researches, this chapter gives a comparative overview of the major challenges faced when dealing with flood hazard. First, definition, source and implication of digital elevation model are explained, and then the focus is on application of different interpolation techniques in drainage network estimation, coupled with advantages and disadvantages of these methods and their application in different research fields. Flood hazard, concepts, definition, types, and causes are defined in the next parts. This chapter also provides a background to climate change and land use change from global to local (Barcelonnette area) which was estimated and interpreted based on different scientific researches.

2.2 Digital Elevation Model: Sources and Implications

Topography representing as digital elevation model (DEM) is an important land-surface characteristic that affects most aspects of the water balance in a catchment, including the generation of surface and sub-surface runoff; the flow paths followed by water as it moved down and through hill slopes and the rate of water movement. All of the spatially explicit fully distribute hydraulic and hydrological models as well as hydrological decision support systems use topography (represented by DEM of the area modeled) to derive bathymetry [1].

Many applications depend on the shape represented by the DEM rather than the absolute elevation values. These include hydrological applications, for which an accurate representation of surface drainage structure is critical [2, 3]. Computation of terrain corrections to observed gravity data and remotely sensed data is another important application that depends primarily on the representation of terrain shape.

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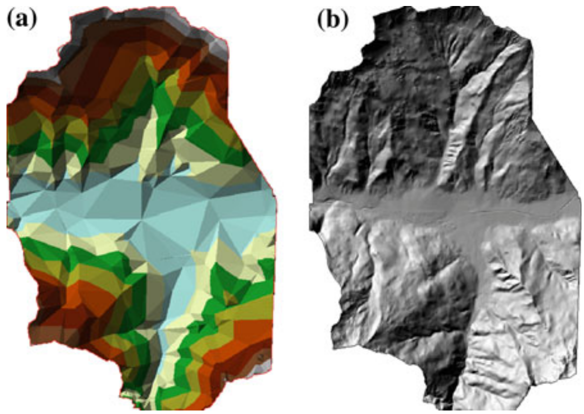


Fig. 2.1 Comparison between two terrains. **a** Irregular DEM. **b** Gridded DEM

The measures of shape most commonly used are slope and aspect of the down slope direction [3].

According to Vaze et al. [1] and Teng et al. [4] DEM is used to derive some key information which is important in distributed hydraulic and hydrological models; such as flow paths; dispersion; and accumulation of water, terrain slope, drainage networks, drainage divides, and catchment boundaries. Vaze et al. [1] also compared the traditional methods of topographic maps, field surveys or photographic interpretation with the application of DEMs. Vaze et al. [1] concluded that DEM is an effective way to present ground surface and extract the hydrological features; thus bringing advantages in terms of processing efficiency, cost effectiveness, and accuracy assessment. Burrough and McDonnell [5] defined DEM as "any digital representation of the continuous variation of relief over space". Wood [6] also defined DEM as "a computer representation of the earth's surface which is provided a base data set from those topographic parameters that can be digitally generated". Alternatively, the DEM could be used in mapping the possible locations of an endangered species whose habitat is altitude dependent. Here, the resultant value for each grid cell may be either the elevation of the center point of the grid cell or the average height of the area covered by the grid cell. The actual characteristics of a grid can be adapted to suit its major application. For instance, the application of the grid may require that all local high points (hills or mountains) in the source data be retained in the grid. Technically, Olivera et al. [7] have another definition for DEM; they defined DEM as an array of squared pixels or cells with an elevation value specific to each pixel. They said that DEM is commonly used in automated drainage analysis methodologies due to its inherent simplicity characteristics of the data structure. Point elevation information in DEM which is a representation of the terrain, can be of two types—*a. irregular and b. gridded* (Fig. 2.1) [3]; a. An *irregular* spaced DEM is often interpreted as a triangular irregular network (TIN). TIN represents a surface as a set of irregularly located points linked to form a network of triangles with z-values stored at the nodes.

The terrain is simulated as a series of planar triangular facets produced by joining all the adjacent points. The assumption that the surfaces are planar is adequate if the points have been chosen at changes in grade in the terrain. The accuracy of the TIN model can be improved by the addition of break lines. These lines represent discontinuities in the terrain surface such as cliffs, ridges, and streams and they indicate where interpolation between adjacent points is invalid [3]. b. In a *gridded* DEM, the elevation points are spaced at a regular interval to create a grid or lattice [3]. DEM represents a surface as a regular grid of locations with sampled or interpolated values.

By incorporating stream lines and cliff lines, a gridded DEM can represent all the discontinuities that can be represented by a TIN and has the significant advantage of being directly compatible with other sources of natural resource data in grid form. It is also readily used by many grid-based applications [3].

Where the gridded DEM has been derived from a primary data source such as contours or a TIN, then the direct relationship between the elevation value and the actual value on the ground, at the respective location, is dependent on the algorithm used to interpolate the grid and the resolution of the grid itself.

The DEM, as its name indicates, is a model of the elevation surface. However, the DEM is often not treated as a model, but is commonly accepted as a "correct" representation of the earth's surface. But, it should not be neglected that DEM data, like other spatial data sets are subject to error. The estimation of errors in a DEM is often not evaluated by DEM users and applicants [8]. Where the DEM is directly observed from aerial photogrammetry or a field survey, the elevation value is truly representative of the value that is found on the ground at the location of that point, provided there is no significant measurement error.

Significant measurement errors can arise due to ground cover by vegetation and buildings, especially when elevations are measured by aerial and space-borne platforms. These measurements are also affected by complex terrain [9]. This is necessary if the DEM were to be used for aircraft flight planning where the minimum flying height of the aircraft is critical. This could also aid the sitting of signal transmitters and receivers, although high points could then have errors in horizontal position by up to half of one grid interval [3]. In areas away from peaks, these values are approximately the same. In general, Burrough [10] and Wise [23] listed the possible errors in DEM data sets as the following:

- Data errors due to the age of data, incomplete density of observations, or results of spatial sampling.
- Measurement errors such as positional inaccuracy, data entry faults.
- Processing errors such as numerical errors in the computer, interpolation errors, or classification and generalization problems.

DEM is usually produced form sampled or observed data points that are used as its source. The contour lines themselves may represent a model of terrain. It can also be acquired directly, for instance photo grammatically from a stereo model or indirectly, from analog cartographic data, satellite images or by field surveying, and so on. Ideally, the data sources are applied without application of interpolation techniques. Application of interpolation techniques is not necessary if the data sources are very accurate, precise, and have high density, especially if the data are derived directly into a regular grid (DEM) [3, 11].

The quality of a derived DEM could vary largely depending on the data source and the interpolation technique. The desired quality also depends on which application the DEM is used; although, a DEM created for one application is often used for other purposes. Therefore, to create any DEM, it is necessary to consider the best available data sources and the best processing technique.

Spurious sinks or local depressions in DEMs are frequently encountered and are a significant source of problems in hydrological applications. Sinks may be caused by incorrect or insufficient data, or by interpolation techniques that does not enforce surface drainage. They are easily detected by comparing elevations with surrounding neighbors [11]. Therefore, detection of spurious sinks features or local depressions in DEMs can lead to improvements in DEM generation techniques as well as detection of errors in source data as indicated above [12].

More subtle drainage artifacts in a DEM can be detected by performing a full drainage analysis to derive catchment boundaries and streamline networks, using the drainage networks creation techniques [13]. Since, applications of DEMs depend on representations of surface shape and drainage structure, absolute measures of elevation error do not provide a complete assessment of DEM quality [2]. Based on the above description about DEM error, it is necessary to make it clear that, in science, the word "error" does not carry out the usual meaning of the term "mistake" or "blunder". The error in scientific measurements means the inevitable uncertainty. As such, errors are not mistakes; the scientists cannot eliminate them; therefore, the best thing to do is ensure that errors are as small as reasonably possible with reliable estimate of how large they are [14]. To this purpose, the starting point in this research was statistical, spatial and hydrological controlling, estimating, and correcting the possible errors in the DEM [15] which will be explained in the next sectors.

2.3 Interpolation Techniques in Drainage Network Estimation

Interpolation methods often assume data points are correct and accurate, but it is assumed that these data points may be subjected to error [5]. The models application to estimate the unknown points may predict the data points exactly (go precisely through the sample data points) or inexactly (approximate the values at the data points). If the observed data points are relatively sparse and irregular or widely spread, interpolation needs to be more sophisticated than for dense, regularly spaced data. The principles of interpolation are shown in Fig. 2.2.

However, regularly spaced data may be subject to bias due to intrinsic frequencies in the data [5]. An interpolation method is working globally, if all data points are evaluated in the interpolation. Local interpolation techniques use only

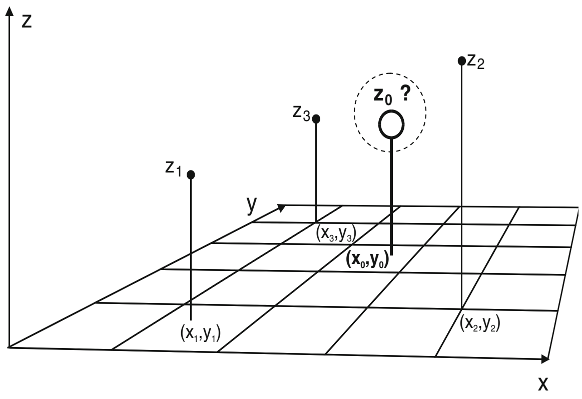


Fig. 2.2 The principles of interpolation technique [16]

data points in a certain neighborhood of the estimated point [16]. The selection of interpolation methods depends primarily on the nature of the variable and its spatial variation [16].

There have been many studies that compare the effectiveness of alternative interpolation techniques, using a wide range of different test datasets and conditions. Overall, it has been found that a number of well-defined factors have a major influence on the quality of interpolation: data measurement accuracy; data density; data distribution; and spatial variability.

These factors are fairly predictable findings, but prior examination of each of these elements may assist in choosing the most appropriate technique for the problem at hand and/or be used in guiding sampling of new or supplementary data sets. Interpolation quality can often be substantially improved through the use of ancillary information, such as remote sensing data or additional environmental information (e.g., location of stream networks) [17]. Having obtained the best possible data set, within budget and time constrains, achieving the maximum usage and value is very important. Hence more general spatial interpolation is required [17]:

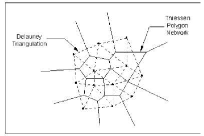
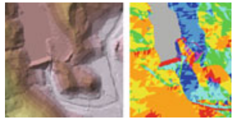
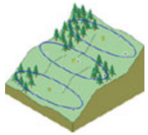
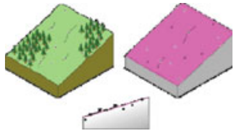
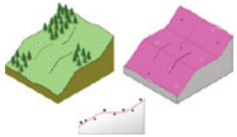
- To convert from one level of data resolution or orientation to another (resampling). Usually, resolution is reduced to the coarsest in a set, but resolution can be increased using a suitable interpolator.
- To convert from one representation of a continuous surface to another, e.g.,TIN to grid or point or contour to grid [17].

There are two interpolation techniques; Deterministic and Geostatistical:

- Deterministic interpolation is directly based on the nearby measured values or on specified mathematical formulas that determine the smoothness of the resulting surface.
- Geostatistical interpolation is based on statistical models that include autocorrelation (statistical and spatial relationships among the measured points).

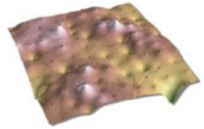
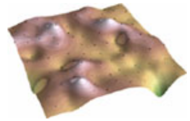
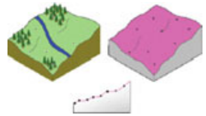
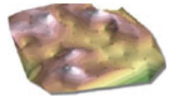
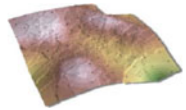
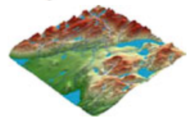
Different interpolation techniques characteristics are summarized in Table 2.1 [17, 19]:

Table 2.1 Different interpolations characteristics (modified information based on [18, 19])

Method	Principle	Advantages	Disadvantages	Best suited scenario	Schematic
Nearest neighbor (NN) and thiessen polygon	Selection of values at closest data point	Ease of use	Inaccurate in less densely sampled scenarios	Densely sampled environmental data	
Triangulated irregular network (TIN)	Set of conterminous with a mass factor is used to define the space	Ability to describe the surface at different levels of resolution	In most cases, required visual inspection and manual control of the network	Dense and moderate distribution of data points	
Polynomial regression (PR)	Fits the variable of interest to the linear combination of regressor variable	Simple model	Model has poor ability to predict outside the range of data points	Moderately dense sampling with regard to global variation	
Global polynominal interpolation (GPI)	Works by capturing coarse-scale patterns in the data, and fitting a polynomial	Computationally less intensive	Estimation errors increase exponentially with increasing complexity	Regions having sparse data points and simple data patterns	
Local polynominal interpolation	Similar to GPI, but the curve is fitted to a local subset defined by windows	Can interpolates short range variations	Misses the global trends in data	Well-distributed data with no discontinues	
Trend surface analysis (TSA)	Separates the data into regional trends and local variations	Assists in removal of broader trends prior to further analysis	Edge effects and multi-co linearity caused by spatial autocorrelation	Important local trends and not so important global trends	

(continued)

Table 2.1 (continued)

Method	Principle	Advantages	Disadvantages	Best suited scenario	Schematic
Inverse distance weighting (IDW)	Linear combination of known points, weighted inversely by distance	Ease to use, and works well with noisy data	Spatial arrangement of samples does not affect weights	Moderately dense sampling with regard to local variation	
Splines	Fits a smooth curve to a series of data points	Visually appealing curves or contour lines	May mask uncertainty present in the data	Irregularly spaced data	
Radial basis functions (RBF)	Similar to the principle of splines, except the curve is not smooth	Required fewer samples	Required good coverage of input space, and not suited for extrapolation	Regions with well distributed data points, though sparse	
Artificial neural networks (ANN)	Learn complex patterns in the available data using Sigmoid functions etc.	Ability to learn and generalize data; works well with sparse data distributions	Risk of poor interpolation caused by over-learning or under- learning	Regions ranging from sparse irregularly distributed data to well distributed data	
Kriging	Similar to the principle of IDW; however, additionally accounts for the spatial arrangement	Best linear unbiased spatial predictor: and no edge effects resulting from trying to force a polynomial to fit the data	Sophisticated programming required; and problems of non stationary in real world data set	Well-distributed data with no discontinues	
Topo to raster	Not specified	Based on iterative finite difference methods. Interpolates a hydrologically "correct" grid from a set of point, line and polygon data	Requires contour vector data as input. Available in ArcGIS based on Hutchinson's ANUDEM program	well-distributed data points	

Application requirements play an important role to expected characteristics of the used DEM. For example, it is not necessary to use high geomorphologic quality of DEM for regional, small-scale analysis and for calculating average altitudes. But geomorphologic accuracy is more sensitive for visibility analyses and even more for analyses that uses algorithms bases on derivates like slope, aspect, cost surface, drainage, path simulation, and so on [15].

Interpolation techniques based on the principles of spatial autocorrelation, which assumes that objects close together are more similar than objects far apart. On the edges of the interpolated area extrapolation is also reasonable. Unfortunately, no one of the interpolation techniques is universal for all data sources, geomorphologic phenomenon or other purposes. It is necessary to be aware that in the praxis, different interpolation methods and interpolation parameters on the same data sources lead to different results. The best chosen algorithms on fair data sources should not differentiate much from nominal ground, that is idealization of our desired model and which is commonly similar to the actual Earth's surface. Divergences between results of interpolation and from nominal ground are especially consequences of the following circumstances [15]:

- Available data sources do not approximate terrain distribution, density, accuracy, etc., of the sources is not appropriate.
- Selected interpolation algorithm is labile (is not robust enough) on the employed data sources.
- Chosen, interpolation algorithms or data structure, are not suitable for selected terrain geomorphology or application.
- Perception or interpretation of the Earth's surface (better: nominal ground) is not the same when more DEM operators work on the same problem; operator's own imagination is common and a reasonable problem in DEM production [15].

Application requirements play an important role to expected characteristics of the used DEM. For example, it is not needed high geomorphologic quality of DEM for regional, small-scale analysis and for calculating average altitudes. But geomorphologic and hydraulic accuracy is more sensitive for visibility analyses and even more for analyses that uses algorithms bases on derivates like slope, aspect, cost surface, drainage, path simulation, bathymetry of the river, and so on [15].

In the most cases, a very high quality DEM should cover all application demands. So it is preferable to find a good and robust interpolation algorithm. Even if a more generalized surface is required, DEM with high detail can be simplified to the required quality. It should be noticed that appropriate generalization methods are very important for producing required DEM. Commonly these methods are complex [15].

The quality of a derived DEM can vary greatly depending on the data source and the interpolation technique. The desired quality depends on the application for which the DEM is to be used, but a DEM created for one application is often used for other purposes.

Any DEM should therefore be created with care, using the best available data sources and processing techniques. Efficient detection of spurious features in DEMs can lead to improvements in DEM generation techniques, as well as detection of errors in the source data, as indicated above.

Since most applications of DEMs depend on representations of surface shape and drainage structure, absolute measures of elevation error do not provide a complete assessment of DEM quality [20, 21]. A number of graphical techniques for assessing data quality have been developed. These are nonclassical measures of data quality that offer means of confirmatory data analysis without the use of an accurate reference DEM [23].

2.4 Flood hazard: Concepts and definitions

World meteorological organization (WMO) [22] reported that floods events are among the most common, costly and deadly of natural hazards and have been a major concern to people residing near rivers and coastal areas throughout history. Despite the great developments in science and technology in recent decades, the hazards of flooding have not been eradicated [24].

According to the European Parliament and the Council of the European Union's directives, the "floods" means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountains torrents, Mediterranean ephemeral water course, and floods from the sea in the coastal areas and may exclude floods from sewerage systems [25].

UN-ISDR [26] also defined flood hazard as the "potentially damaging physical events, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation".

Wassef and Aysan [27] discussed the geographical distribution of disasters and compared the flood hazard to other natural phenomenon in their research and found floods as the worst phenomenon that affected people's lives. According to Davis [28] investigation, there were 118 major flood events from the biblical deluge to the present, and Wasseff [29] also listed 87 floods during the period of 1947–1991 which resulted in homelessness of at least 50,000 people. In 1887, one of the worst recorded flood event occurred along the Yellow River in China. This flood resulted in at least 1.5 million deaths and caused as many as 10 million homeless ([28]. During 1982–1991, flood events left approximately 21,000 deaths per year and affected 73 million persons per year [27]. The investigation results of Wijkman and Timberlake [30] and Wasseff [26] indicate that since 1960, each passing decade shows an increase in the number of flood disasters, and the number of people which were affected by these flood events. Yen and Yen [31] has also shown that relative flood damages in the USA as a fraction of the annual Gross National Product, which expressed a declining trend between 1929 and 1993. More recently, flooding has occurred in Pakistan in 2010, which has directly affected approximately 20 million people, mostly by destruction of property, livelihood and infrastructure, and left about 2,000 dead [22].

Climate change as huge natural variability and long-term persistence phenomenon is realized as an important factor which affects on flood events but make it difficult to realize any trends in extreme weather events. During recent decades, flood damages in Europe have increased considerably [32]. According to previous investigations which have focused in Europe, in a large part, this increasing trend in flood hazard can probably be also attributed to human behavior, such as developing urbanization in flood plains [33].

2.5 Types and Causes of Flood Events

Lowland flood-prone areas can be found all over the world, along the coasts, in the river floodplains, and as inland depressions. Generally, they are basically unsuitable for development by their nature; sensitive areas with high physical conditions and environmental value. However, due to their strategic location and/or suitability for agriculture activities, there is often a tremendous pressure to develop these areas for various type of land use beneficial purpose. Therefore, a rapid population growth, significant increase in agricultural exploitation, urbanization, and industrialization may be observed in these lowland and flood-prone areas. Due to this, Schultz [34] mentioned that such areas become increasingly vulnerable from extreme weather conditions that will have their effect on the requirements for any drainage and flood-hazard management.

Floods include river floods, urban floods, coastal floods, and sewer floods. They can be caused by meteorological major causes such as; (a) Intense and/or long lasting precipitation or rainstorms on a small scale which cause flash floods. According to WMO [35, 36], flash floods typically occur by convective precipitation at high intensity, in short duration (less than 2–6 h) and limited aerial extent (less than 1,000 km^2); (b) widespread storms, which are caused by flooding on a regional scale. For regional flooding, the range of rainfall duration may differ from several days to a week or, in exceptional cases (in very large watersheds), may be associated with multiple storms occurring over a period of several months, such as in the 1993 flood in the Upper Mississippi River basin or the 1998 flood in the Yangtze River basin. Other meteorological causes of floods may be grouped into (c) Snowmelt; and (d) Reduced conveyance due to ice jams or landslides broad categories. Snowmelt floods are the result of three factors. The existence of the snowpack (aerial extent and depth), its condition (temperature and water content) and the availability of energy for melting snow. Snowmelt occurs when energy is added to a snowpack at 0 °C. In snow-dominated regions, some of the largest floods are caused by warm rain falling onto a snowpack at this temperature. In very large, snow-dominated watersheds, the annual peak flow is nearly always caused by snowmelt, whereas either snowmelt or rainstorms can cause the annual peak in small or medium-sized watersheds. In the cold regions, extreme high water stage can be caused by snow obstructing very small channels or ice jams in large rivers. In the case of rainfall or snowmelt flooding, natural processes can be exacerbated by watershed changes that enhance runoff production, cause flows to move more rapidly into the channel, or cause flows to move more slowly or more quickly within the channel. Thus, deforestation, overgrazing, forest or bush fires, urbanization and obstruction, or modification of drainage channels can be extensive or so severe as to have a significant effect on flooding.

Tropical cyclones produce hazards from storm surges, to wind and river flooding. Earthquakes and volcanic eruptions can produce landslides that cause flooding by damming rivers. Volcanic eruptions are associated with hazardous mudflows, and volcanic ash may cause flooding by choking river channels. From a natural hazard perspective, there are important similarities between river flooding; lake flooding; flooding resulting from poor drainage in areas of low relief; and flooding caused by storm surges (storm-induced high tides), tsunamis, avalanches, landslides, and mudflows. All are hazards controlled, to some extent, by the local topography, and to varying degrees it is possible to determine hazard-prone locations. Mitigation and relief efforts are also similar [22].

Although the influence of these causes could be strongly affected by some other factors, for example, rainfall and sea levels are two major causes of floods, and are natural and uncontrollable phenomena. However, these natural phenomena which results in flood damage are very much influenced by human behavior such as: deforestation in the upper catchment area, straightening of rivers and suppression of natural flood plains, inadequate drainage practices, and extensive building in high risk flood areas [37]. Apart from nonclimatic factors that affect flood events, there have been adverse flood-hazard changes due to climate change, e.g., increasing potential for intense precipitation in the warming world. The scientists in WMO also believe that there is no doubt, with currently available scientific data, that climate is changing in the sense of global warming. Global warming, whatever be the eventual magnitude, will very certainly affect the location, frequency, and strength of meteorological hazards [22].

Nonetheless, this research deals with the Ubaye River floods, thus river flooding will be the focus of this research. Floods along the rivers are natural and an inevitable part of the resident's life. River Floods depend on precipitation intensity, volume, timing, antecedent conditions of rivers, and their drainage basins (e.g., presence of snow and ice, soil character, wetness, urbanization, and existence of dykes, dams, or reservoirs) [38–40]. Some floods occur seasonally with winter or spring rains; coupled with the melting of snow, the river basins would fill with too much water too quickly. Torrential rains from decaying hurricanes or tropical systems can also produce river flooding [41]. Communications from the commission to the council (the European parliament) report that river floods also may occur whenever the capacity of the natural or man-made drainage system (such as dams, dykes) is unable to cope with the volume of water generated by rainfall, or when flood defenses fail. These are of the most common causes for river flooding in Europe [37]. Damaging floods will increase magnitude, when the capacity of the main conveyance of the river channel is exceeded. The main conveyance may be the primary channel of a river without dykes or the area between the dykes for a river with dyke. The capacity of the channel may be exceeded as a result of excessive flow distribution or ice or debris jams which could block the flow.

According to theoretical background and previous research regarding to flood, it is widely acknowledged that anthropogenic behaviors affect floods and flood hazards. Land use change can affect the amount of runoff for a given storm and the rapidity with which it runs off. Human occupancy of floodplains increases their vulnerability due to exposure to flood hazards. Dams, levees, and other channel alterations affect flood characteristics. Increased occupancy of floodplains and larger floods due to deforestation and urbanization has been attributed also to increase flood damage. Deforestation and urbanization increase flooding because they decrease the capacity of the land to absorb rainfall. It is customary to assume that flood hazards are stationary, i.e., they do not change with time. Climate change, anthropogenic influences on watersheds or channels, and natural watershed or channel changes have the potential, however, to change river flood hazards.

2.6 Climate Change and its Variability in Europe

In the past, destructive flooding maybe caused by only extremely heavy precipitation. Nowadays, less extreme precipitation may lead to a serious floods event [42]. Therefore, apart from nonclimatic factors that have affected flooding, there have been adverse flood-hazard changes due to climate change, e.g., increasing potential for intense precipitation in the warming world. The scientists in WMO also believe that there is no doubt, with currently available scientific data, that climate is changing in the sense of global warming. Global warming, whatever be the eventual magnitude, will very certainly affect the location, frequency and strength of meteorological hazards [22]. Many investigators believe that climate change is expected to have substantial impacts on hydrology on global, regional, and local scale [43, 44]; Andréasson et al [43]; [38–40, 40, 46]. There is also strong evidence that rainfall changes associated to global warming are already taking place on global and regional scale. The trend was globally positive throughout the twentieth century, although large areas were characterized by negative trend [38–40]. Since the report of Intergovernmental Panel on Climate Change [47] raised this question that "Has the climate become more variable or extreme?" Analyzing trends in climate extreme parameters have received increasing attention from many researchers in a variety of climatological and hydrological studies. Several previous studies concerning long-term climatologically trends have focused on surface air temperature and precipitation. For example, Lettenmaier et al. [48] analyzed trends in precipitation, over the continental USA by applying the Mann–Kendall test, the results of his research showed an increase in precipitation during autumn in a quarter of the entire stations. Increasing trend in precipitation was reported by some other researchers in Australia and New Zealand [49, 50] and Argentina [51]. On the other side, decreasing trend in precipitation was the result of research which was found in the Russian Federation [52], China [53], Turkey [54], and Africa [55, 56].

Heino et al. [57] have distinguished that there is an increasing trend in minimum temperature almost everywhere and increasing trend in maximum and mean temperature in northern and central Europe. Over the Russian Federation, Canada [58] and in Australia and New Zealand an increasing trend in maximum and mean temperature was also observed [49]. These results confirm the outcomes of Smit et al.'s investigation [59] which indicate that mid-latitude regions such as the mid-western USA, southern Europe and Asia are becoming warmer and drier, whereas the lower latitudes are becoming warmer and wetter.

IPCC [38–40] reported that, during recent decades, precipitation has tended to increase in mid-latitudes, decrease in the Northern Hemisphere subtropical zones, and increase generally throughout the Southern Hemisphere. Lettenmaier et al. [48], Türke [54], Zhang et al. [60], Gonzalez Hidalgo et al. [61], Gong et al. [62], del Rio et al. [63], and Partal and Kahya [64] are some examples of the researchers who have investigated recent rainfall trends and confirm the IPCC claim about increasing and decreasing precipitation over the mentioned locations. Extreme temperature series have also received increased attention during the last decades of the twentieth century [65, 66].

The research analysis on temperature records across the world indicates there has been an increase in the mean global temperature of about 0.6 °C since the start of the twentieth century [67–69]. Mearns et al. [70] and Hansen et al. [71] concluded that small change in the mean temperature could produce substantial changes in the frequency of the extreme temperature. Increase in temperature trend of the planet has been particularly observed since 1920s [72].

According to IPCC and recorded investigations of previous researches, many regions over Europe are vulnerable to climate change impacts. The updated report of European environment agency (EEA) and intergovernmental panel on climate change (IPCC) confirms that the warming trend in Europe was above the global average mentioned since pre-industrial times. During the twentieth century, most of the Europe experienced increasing trend in average annual surface temperature with the stronger warming in winter which was observed over most regions. The 1990s were the warmest in the instrumental record.

According to IPCC [38–40], there was a 10–40 % increasing trend in precipitation in the twentieth century in northern Europe but, on the other hand, there was up to a 20 % decreasing trend in the southern part of Europe. IPCC also realized a global rising in temperature from 1.8 to 4.0 °C (3.24–7.2 F) in the twentieth century. This Projection over Europe also showed a 1.0 and 5.5 °C (1/8–9.9 F) increasing trend in temperature. This report also emphasized that there was more frequent, intense, and increasing number of hot extremes and a decreasing number of cold extremes over the past 50 years, and these trends are projected to continue.

According to updated information of Jones and Moberg [73] the warming trend between 1901 and 2005 throughout Europe was established at +0.90 °C and precipitation trends were more spatially variable. Table 2.2 shows trend analysis throughout Europe between 1977 and 2000.

Table 2.2 Trend analysis results throughout Europe between 1977 and 2000

Location	Trend	Source
Throughout Europe	Increasing trend in temperature about +0.90 °C	[73]
Central and north-eastern Europe and in mountainous regions	Increasing trend in temperature is higher. Higher trend of daily temperature due to an increase in warm extremes, rather than a decrease of cold extremes.	Böhm et al. [136]; Klein Tank and Können [137]; [73, 136, 137]
Mediterranean region	Increasing trend in temperature	Böhm et al. [136]; Klein Tank and Können [137]
In most parts of the continent	Lower trend in mean precipitation per wet day.	[136, 138, 139]
In most of Atlantic and northern Europe	Increasing in mean winter precipitation	[136]
Mediterranean area	Negative trend in annual precipitation in the east, while they are non-significant in the west.	[140]

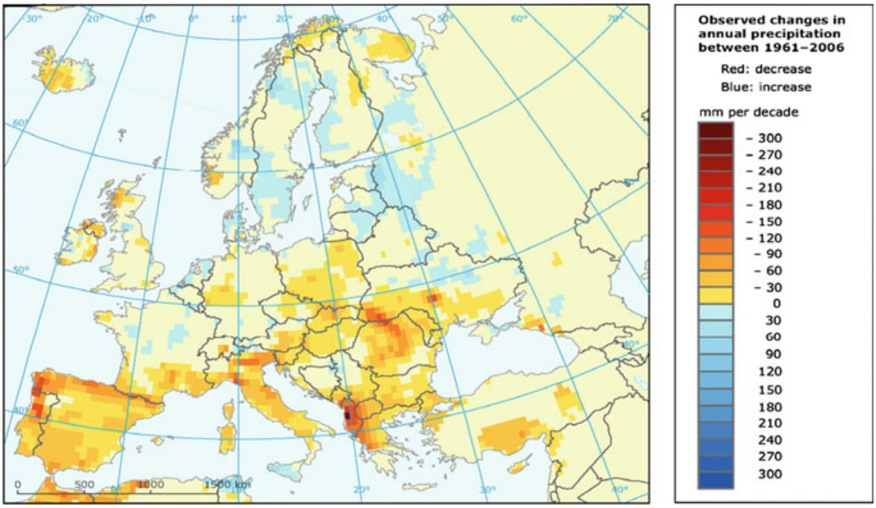


Fig. 2.3 Observed change in annual rainfall 1961–2006 (*Source* EEA's "Global and European temperature" core set indicator, based on gridded data from CRUTEM3, climatic research unit and KNMI's climate explorer)

Figures 2.3 and 2.4 show observed changes in annual precipitation and temperature between 1961 and 2006 over Europe, which was reported by EEA.

According to the robust result of IPCC [38–40], a downward trend in summer precipitation in southern Europe, accompanied by upward trend in temperatures, which enhance evaporative demand, would inevitably lead to reduced summer soil moisture [74]. Figure 2.4 shows the European mean annual temperature deviations

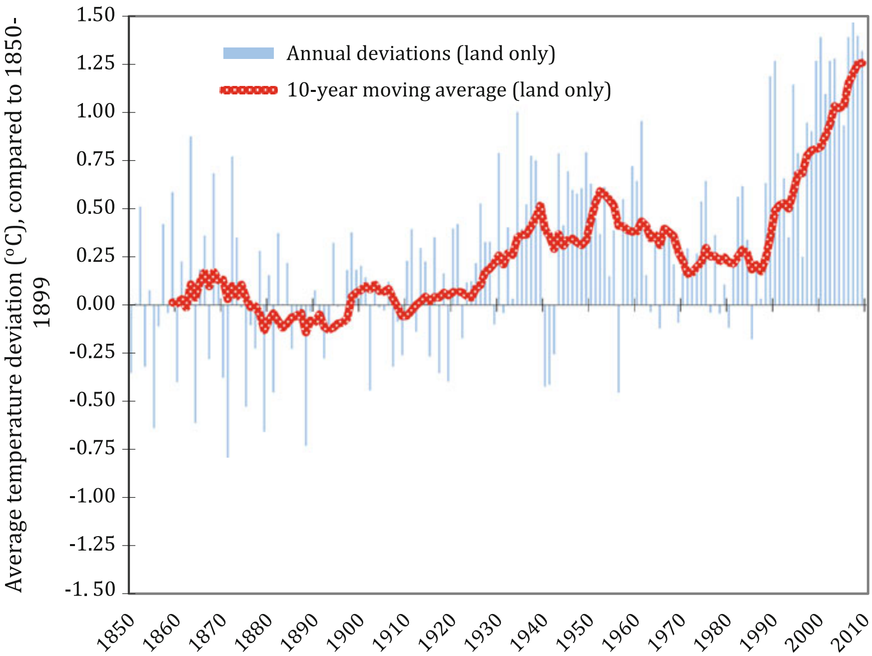


Fig. 2.4 European annual average temperature deviations, 1850–2009, relative to the 1850–1899 average (in °C). The lines refer to 10 year moving average, the bars to the annual "land only" European average; (*Source* EEA's 'global and European temperature' core set indicator, based on gridded data from CRUT)

which are in the source in relation to the base period between 1961 and 1990. To better monitor the EU objective not to exceed 2 °C above pre-industrial values, the annual deviations shown in the chart have been adjusted to be relative to the period between 1850 and 1899. Over Europe, average annual temperatures during the real pre-industrial period (1750–1799) were very similar to those during 1850–1899.

Figure 2.5 shows the 10 year moving average of the annual, winter (December, January and February) and summer (June, July and August) mean temperature deviations in Europe 1860–2009. It seems that since 1990, the annual, summer and winter variables trend in temperature over Europe was increasing. Observed temperature change over Europe 1976–2006 is shown in Fig. 2.6.

In all figures, the increasing trend in temperature over Europe is obviously clear. The increases for winter in northern Europe and in summer for southern Europe were higher.

The IPCC report also mentioned that Europe's climate was already being affected by warming in several ways; for example, the snow cover has decreased by 1.3 % per decade in the last 40 years.

According to IPCC [75], WMO [22] and McCarthy et al. [76] the strongest potential impact of climate change on human settlements is believed to be flooding [75, 22], McCarthy et al. [76]. Climatic parameters are one of the most important

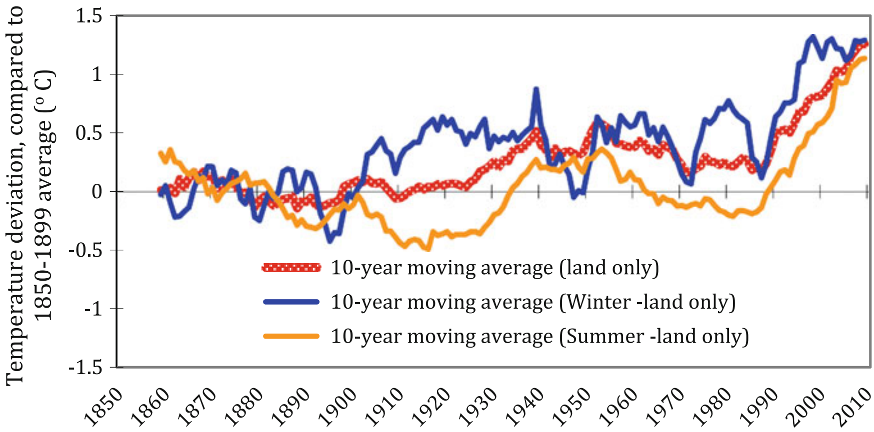


Fig. 2.5 Annual, winter (December, January, February) and summer (June, July, August) mean temperature deviations in Europe, 1860–2009 (°C). The lines refer to 10 year moving average European land; (*Source* EEA's "global and European temperature" core set indicator, based on gridded data from CRUTEM3, climatic research unit and KNMI‘s climate explorer)

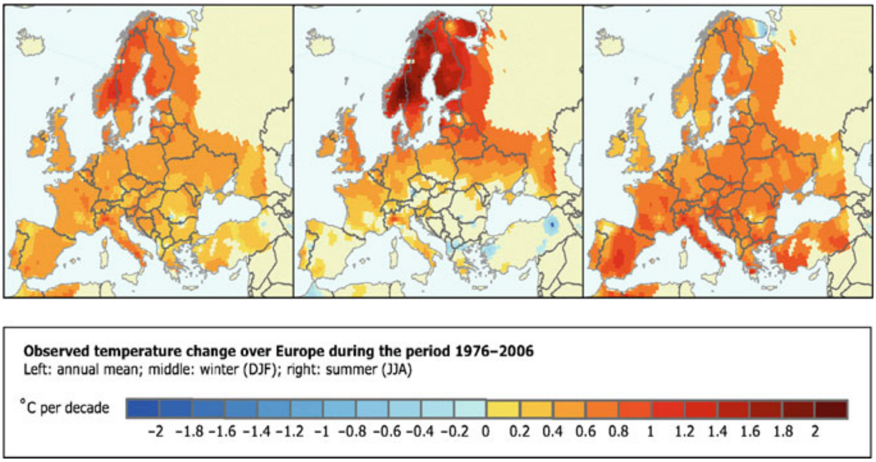


Fig. 2.6 Observed temperature change over Europe 1976–2006; (*Source* EEA's "Global and European temperature" core set indicator, based on gridded data from CRUTEM3, Climatic Research Unit and KNMI's climate explorer)

triggering factors for floods event. The trend analysis of hydrological and meteorological series is important, even more relevant when considering the regional effects of global climate change [22, 77]. As the atmosphere's water holding capacity increases with temperature, the intensified potential for extreme precipitation events augments the risk of inundations caused by sustained rainfall over most land areas [39, 78], especially in areas where flooding is typically triggered by intense summer rain [33]. Alternatively, decreases in snow and river-ice cover reduce the frequency and severity of snowmelt-related and ice-jam floods [79–83]. To date, relatively few researches have made a quantitative assessment of the potential impacts of climate change on extreme river flows in Europe. These studies were applied in some regions by different scientists; UK: Kay et al. [84]; Scandinavia: Graham et al. [85]; the Benelux countries: Booij [86]; and Germany: Shabalova et al. [87]. While some of the investigators realized an increasing trend in flood frequency and intensity, the other investigators found a decreasing trend.

Application of different climate scenarios as well as hydrological models made it difficult to compare the results and to make a picture at a European scale. Lehner et al. [88] analyzed the changes in flood frequencies due to global climate change over Europe, and found northern to north-eastern Europe to be mostly affected by global climate change, and distinguished an increasing flood risk in those areas. However, their investigation was based on applying the climate change signal of two different general circulation models (GCMs), not based on an observation-based dataset. They also did not take into account a potential increase in climate variability [88].

Additionally, from natural features point of view in the climate systems, the global climate change is also related to anthropogenic influences [89, 90]. The effect of human beings on hydrological time series therefore should be of great attention around the world. The example of increasing temperature and decreasing precipitation since the mid1960s as a result of deforestation was presented by Kothyari and Singh [91]. Similarly, Meher-Homji [92] showed decreasing precipitation trends because of increasing deforestation. Sharma et al. [90] also showed some evidence of increasing temperature and decreasing precipitation and discharge particularly during low flow season, as a result of land use change, and anthropogenic effects.

2.7 Climate Change Scenario for Barcelonnette Area

For Barcelonnette area, there are only a few studies about estimation of climate change scenarios with focusing on landslide. In one example, influence of climate change scenario on slope hydrology and landslide frequency is investigated by Malet et al. [93].

They applied climate change scenarios of GCMs and analyzed a future scenario for the period of 2069–2099 based on observed data between 1969 and 1999. The results of impacts of climate change based on the A2 scenario are shown in the Fig. 2.7. According to Malet et al. [93], the main results from this investigation for Southeast France ere: (a) higher temperatures in summer; (b) more rainy winters; (c) drier summers; and (d) a decrease in soil water content.

In another example, Buma and Dehn [94] investigated also the prediction of climate change impact on slope stability using downscaled climate data and slope hydrology/stability model. They applied three scenarios for the period of

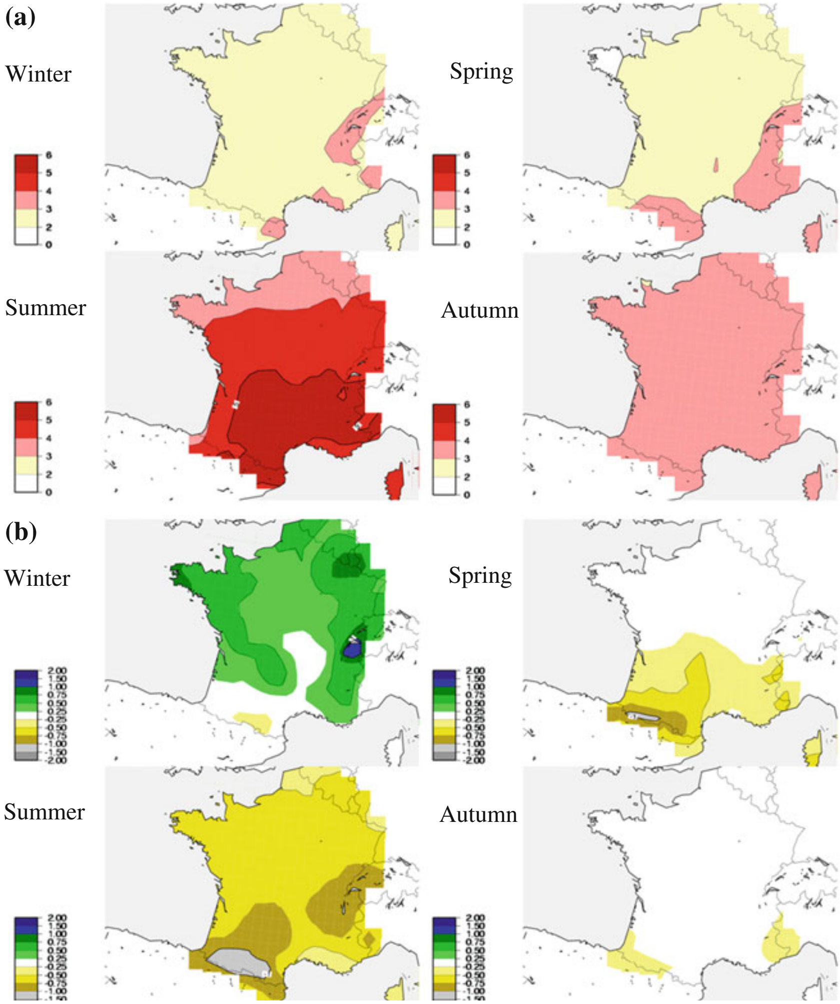


Fig. 2.7 Impacts of climate change based on the A2 scenario of GIECC. **a** Changes in temperature. **b** Changes in precipitation [93]

1971–2000; 2021–2050 and 2069–2099 according to the observed data between 1928 and 1970. In this research, they found a decreasing in local winter precipitation in Barcelonnette area. Buma and Dehn [95] in another study investigated the effects of climate change on landslide in South East France. They found that precipitation increased in winter and spring, and decreased in summer and autumn, using the reference period of analog-downscaling with HCGS between 1950 and 1979.

2.8 Land Use Change and Anthropogenic Factors

Apart from climatic factors that have affected floods (as mentioned in Sect. 2.6), according to Kundzewicz and Schellnhuber [96] another significant reason, for increasing flood hazards can be related to nonclimatic anthropogenic factors: Changes in socioeconomic systems include land-use changes such as deforestation, urbanization, elimination of floodplains area, as well as river regularizations [96], which lead to reducing of water storage, reducing of infiltration capacity, and increasing of runoff coefficient [97]. WMO [22] also reported that the first category of nonclimatic anthropogenic factors effects resulting from human actions which have affect on the ecosystem changes are deforestation and urbanization. These lead to changes in the ecosystem that magnify the consequences of heavy precipitation, converting this precipitation into floods of a greater severity than otherwise would have resulted [22].

Xiaoming believes that land use change is a major reflection of the land ecosystem change, which will then lead to the hydrology regime changes. The hydrology regime changes can then feedback on environmental and land use change, which generates a complex and international system.

By floodplain development, increasing accumulation of population and wealth in flood-prone areas, humans have been driven to occupy unsafe areas (e.g., informal settlements on floodplains), thereby increasing the loss potential.

Where urbanization occurs on the floodplain, the ability of the floodplain to attenuate a flood peak by promoting storage, infiltration, and alternative flow pathways is reduced. This effect is greatly enhanced where flood defenses are erected; such structural measures may also cause residents to lose their sense of natural river dynamics and reduce the perceived risk for further development [98].

The history analysis of urban growth indicates that urban areas are the most dynamic places on the earth's surface. Despite their regional economic importance, urban growth has also a considerable impact on the surrounding ecosystem changes [99]. In the last few decades, an increase in urban areas has occurred in the world, and demographic growth is one of the major factors responsible for these increasing changes. By 1900 only 14 % of the world's population was residing in urban areas, but it had increased to 47 % by 2000 [100]. Urban growth is a common phenomenon in almost all countries over the world. Currently, increases in urban areas are the major environmental concerns that have to be analyzed and monitored for any future planning.

Urbanization and its increasing trend may have particularly severe influences on small catchments, where a high percentage of the catchment area may undergo a change in land use within a short time period. In a larger catchment, the effects of land use change would to a greater extent be damped by the remainder of the catchment area [101–103]. Since the end of the 1960s, the scientific literature reported the results of studies on the possible effects on the fluvial regime of intense deforestation and urbanization which had occurred in some drainage basins of the United States [104]. Some previous studies also have analyzed the effects of intensive land use change, such as the construction of roads close to the rivers in mountainous areas (as a type of land use change and anthropogenic activity), can induce on the river runoff which then increase [105].

These studies highlighted that the hydrological effects of human activity are strictly dependent on the extension of the area affected by the man made intervention. For instance, similar analyses were performed in a tropical watershed by Costa et al. [106]; he realized that a deforestation of about 30 % in the basin induced a 24 % increase in annual mean discharge. Therefore, it might be concluded that land use change, in particular deforestation, has been credited with causing important increases in the frequency and severity of flood events. In another simulation, the research performed by Brath and Montanari [107], the higher sensitivity to land use change of the low flows has been also investigated. Recently, Naef et al. [108] reached similar results and conclusions by addressing a river basin located in Germany. They found that the flood runoff reduction by land use change can be remarkable in the presence of rapid run-off production only. In the last two decades, a lot of research has been carried out to estimate the effects on the hydrological cycle induced by vegetation cover changes, with particular emphasis on deforestation consequences [109], urbanization of bottom valley areas [110], construction of roads in forests [111, 112], and conversion of wooded areas to pasture [113]. In recent decades, the scientific investigation shows that a lot of inundation has occurred in Europe causing loss of human lives and financial damages which have been aggravated, in several cases, by the intense urbanization of flood-prone areas [114]. Based on the European parliament's report, land-use changes in Europe have lead to a reduction in the storage volume and an increase in the run-off coefficient. Sullivan et al. [115] studied a basin in Cornwall which had a significant increasing trend in magnitude and frequency of flood flows, but only a weak decreasing trend in rainfall. Although they suggested that the increasing in flood flows could be attributed to land-use change. Other researchers have also suggested that this interaction of different forcing factors could be exploited, for example by offsetting urbanization with forestation, or climate change by land-use change [108, 116, 117, 118]. The effect of land-use change was studied also by Bultot et al. [119], who analyzed the influence of land use on the water balance of the near surface soil layer by applying a conceptual rainfall–runoff model to a Belgian river basin. They concluded that the presence of vegetation can induce effects on the river flows that are more evident in arid climates where the vegetation cover causes a reduction of the river discharge that is more marked for the lower river flows. Increases in urban areas tend to increase the responsiveness of an area to a rainfall event, usually leading to flash flooding and increased maximum rates of stream flow. Infrastructure planning and implementation, as part of a regional development plan of an urban area, contributes greatly to mitigate damages of flood events. It should be considered that while infrastructure planning and implementations reduce flood damage from small and medium floods; they can induce catastrophic floods when they start to fail. For example, if dykes or levees fail, they can cause a false sense of security on public and residential parts in flood-plain areas. As noted by Eiker et al. [120] for flood-mitigation projects, the question is not if the capacity will be exceeded, but what are the impacts when the capacity is exceeded. Thus, land-management planners and the public must fully understand the consequences when the dykes or dam fails.

2.9 Historical Changes in Land Use in Barcelonnette Area

One of the reasons for deforestation during the seventeenth century in France was that the forests were considered as an economic resource spatially for the consideration of warships. The dramatic consequences of deforestation led to increasing of land degradation and mass movement occurrence [121]. Many authors have addressed in their investigations to deforestation in the floodplains of the rivers in south-eastern France in the late eighteenth and nineteenth centuries [122]. In contrast, with the vegetation explosion of the early twentieth century, changes were observed over shorter time periods and in smaller areas, in the riparian forest active channel contacts. Table 2.3 summarizes previous investigations on land use, channel morphology and population change during eighteenth, nineteenth, and twentieth centuries in whole catchment:

Bravard [123] by investigation on previous research concluded that anthropogenic factors played a major part in initiating active channel restriction at the turn of the century, with climate change as a secondary factor. Slopes were stabilized through extensive reforesting, torrent control measures, and progressive abandonment of agro-pastoral activities, thereby reducing peak flow and bed-load supply. Bravard [123] also confirmed the importance of natural and anthropogenic factors in riparian vegetation in his research. The evolution of the Ubaye Riverbed at the turn of the twentieth century provides an instructive example of short-term watershed influence on a river segment. As shown by Schumm [124], channel geometry is equally adjusted to external factors and is modified at the same time as riparian vegetation. Channel deepening and narrowing on the major part of the Ubaye course was noted, as well as channel pattern modification. By increasing hydraulic roughness and favoring bar stabilization, forest expansion exerts an internal control on the alluvial mosaic and contributes to a reduction in bed width. The genesis of a floodplain forest is, in fact, accompanied by the development of tree units within the active channel, and therefore rivers draining forest corridors are generally not as wide as those located in prairie sectors [125]. Internal factors,

Table 2.3 Summarizing historical land use change

Years	Changes	Source
1830	In 1830, the Ubaye river occupied most of the valley bottom, whereas agricultural land use extended up to the edge of the active channel.	[141]
Since 1860	The mobility of channel-forest contact the cyclic evolution of the forest margin-active channel contact during the recent period appears to be controlled by fluctuations in hydrology and bed-load. The population decreased by 50–60 % in the Barcelonnette basin and by more than sixfold in the upper valley. Since 1860, when the population peaked in this region, the population has decreased by 75–80 %.	[141]
As early as 1892–1905	During this time 3,500 ha were reforested with Austrian black pine while 8,589 ha had already been reforested (Figs. 2.8, 2.9)	[142]
1920–1925	In 1920 Riparian forestation started. The riparian forest development in the active channel between 1920 and 1925 was the result of reduced rejuvenation processes like peak flow and bed load supply, mainly due to a slope afforestation policy and torrent correction works undertaken in the late nineteenth century by the RTM agency (law of 28 July, 1860).	[141]
1920–1930	The active channel area was colonized by Pinus Sylvestris. Dendrochonological analysis shows that forest recolonization of the active channel took place around 1920–1925 based on age of Pinus Sylvestris. Recolonization was accompanied by fluvial metamorphosis, changing from a braided pattern to a sinuous single-bed pattern, as well as by bed incision. The topographical cross-section of this sector demonstrates that the actual bed is 2 m lower than it was 75 years ago.	[141]
1941–1957	Close chronological ties with active channel expansion (+12.3 % from 1948 to 1956).	[141]
Between the first third of the nineteenth century and 1948	The area of active channel decreased from 246 to 252 ha to 174 ha.	[141]
1948–1973, notably between 1948 and 1956	Vegetative colonization of the active channel primarily affected the segment upstream from Barcelonnette where the forest decreased by 44 %. Such decreases were also occasionally observed downstream, but not in any case throughout the entire period. Reduction of forest area in favour of the active channel area. These changes, lasting only two decades, were in opposition with the trend observed at the beginning of the century.	[141]

(continued)

Table 2.3 (continued)

Years	Changes	Source
After 1950	Spatial fluctuation of forest-channel borders occurred.	[141]
1957	Flood 1957 impacts had been largely attenuated below the braided section upstream from Barcelonnette. The exceptional dimensions of the floodplain in this sector greatly contributed to attenuating the flood, favoring bed load deposition. Thus, the millennial flood caused comparatively little damage to the riparian vegetation in the study area, excepting the upstream sector which is characterized by specific changes. Conversely, dykes downstream were destabilized by a 0.5–1 m bed incision. The 1957 flood also reduced channel slope and hydraulic power upstream from Barcelonnette, which explains the adjustment of vegetation and bed geometry over the ensuing decades. These adjustments are ongoing at this site, whereas they have not been observed since 1982 downstream from Barcelonnette.	[143]
1948–1990	In fact, sector analysis from 1948 to 1990 shows a complex geographical evolution. The forested areas were almost stable as tree units went from 209 ha to 196 ha show a slight reduction of 6 % (Fig. 2.10). The active channel was also restricted during this period mostly due to human installations developed in the corridor downstream from Barcelonnette.	[141]
1970–1990	In contrast the 1970–1990 periods is characterized by reduced peak flow and vegetative recolonization (+5 %) of the active channel (Fig. 2.11).	[141]
The 1973–1990	The sector located upstream from Barcelonnette showed major continuous vegetation colonization of the active channel. Whereas downstream, these changes were discontinuous and were only apparent between 1973 and 1982. The forest progression and additional restriction of the active channel (Fig. 2.12). The forest gained only 9 ha, whereas the active channel lost 40 ha, as a result of human modification (water treatment stations, camping grounds, and public dump sites).	[141]
1982 and 1990	A great part of the active channel was colonized by pioneer units. These units were observed in the 1982 aerial photographs, (+19 ha).	[141]
Early twentieth century	Changes were observed in the riparian forest active channel contacts over shorter time periods and in smaller areas. Forest covered only 10.3 % of the watershed in the early nineteenth century, but from twentieth century, occupies 33 % of the watershed area. This recolonization has affected all the local districts, as 70 % of them have more than doubled in forested area (Figs. 2.13, 2.14).	[141]

(continued)

Table 2.3 (continued)

Years	Changes	Source
At the end of the nineteenth century, during the twentieth century	The reach located upstream from Barcelonnette was characterized by a dynamic equilibrium corresponding to high peak flow and abundant bed-load. This segment is typical of alpine fluvial landscapes which registered major modifications between the late fourteenth century and the nineteenth century, evolving toward active braiding. While for many years mountain populations were considered to be responsible for this evolution, recent views have focused on the influence of the little ice age climatic degradation, affecting slopes whose vegetation cover was altered by overgrazing. This led to an intensification of flooding and to an increased bed-load supply which, in turn, produced channel aggradations and widening. Thus, the Ubaye occupied the entire valley flat when human society exploited slopes to the fullest, by combining dominant pastoral activities with subsistence crops.	[144, 20, 145]

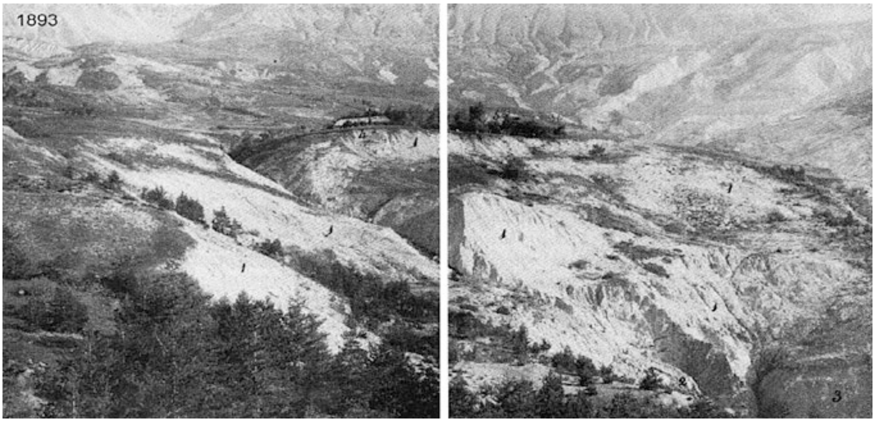


Fig. 2.8 An evolving land use: intense deforestation in the eighteenth century (agro-pastoral communities); intense gullying (*source* RTM)

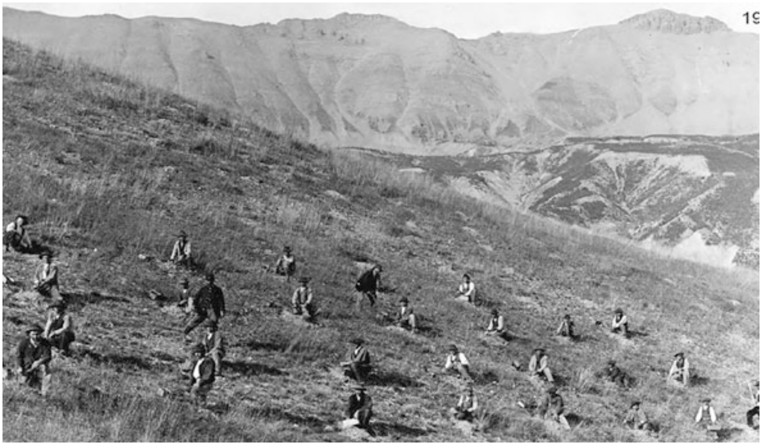


Fig. 2.9 An evolving land use: intense deforestation in the nineteenth century (agro-pastoral communities); intense gullying (*source* RTM)

which are biological or physical, are in fact interrelated and adjusted with the external factor changes. This afforestation is different from situations observed downstream of flood control dams [126]. Its evolution is more progressive and more long term, as riparian vegetation eventually adjusts to natural hydrological variations. This phenomenon also differs from other cases of piedmont river evolution where vegetation metamorphosis has been found to be due to floodplain abandonment by farmers [127].

Fig. 2.10 An evolving land use: intense deforstation in the nineteenth century (agro-pastoral communities); intense gullying (*source* RTM)

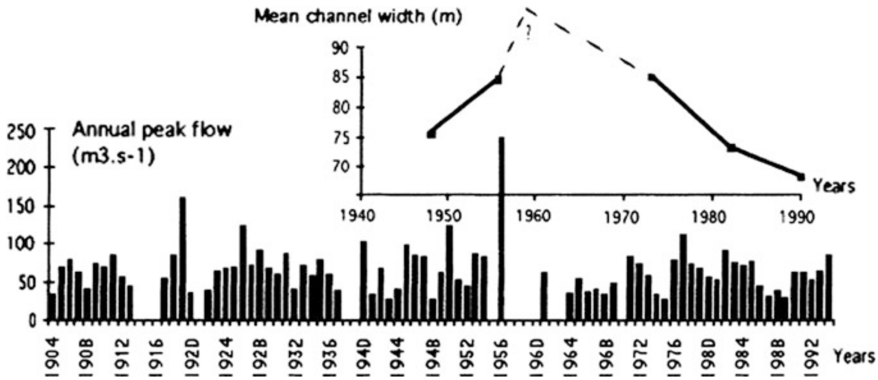


Fig. 2.11 Evaluation of active channel average width and annual peak flow from 1945 to 1990, on the middle Ubaye (After Hydro bank data and aerial photographs) (*source* RTM)

Fig. 2.12 An evolving land use: intense deforestation for torrential control during the twentieth century: 1987 (*source* RTM)

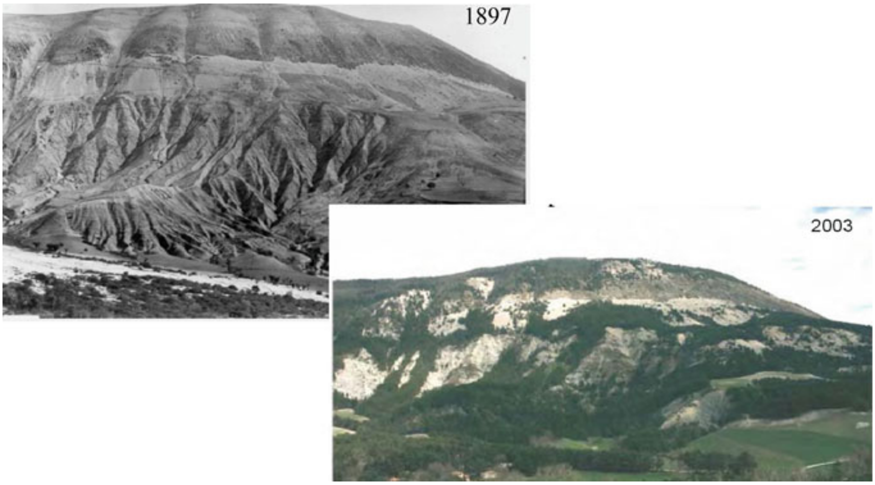


Fig. 2.13 An evolving land use: during the twentieth century, intense reforestation for torrential control (*source* RTM)

Fig. 2.14 An evolving land use: during the twentieth century (*source* [93])

2.10 Physical Characteristic of Flood Hazard

In the frame of hazard assessment, flood events are analyzed by means of recurrence intervals and spatial–temporal flood characteristics [128]. Flood hazard estimation is based on the factors such as the triggering factors causing the hazard, their spatial extent, duration and time of onset, including their frequency and magnitude of occurrence, and secondary events influencing the event if any [129]. The flood characteristic creates a clear understanding of the flood plain, and gives the understanding to the flood hazard behavior. The flood characteristic is not only described by flood inundation, but also by inundation depth, flow velocity, inundation duration; volume of water, surface area, stream power, and so on. Access to all this information is possible by flood simulation using hydrodynamic modeling.

Alkema [130] emphasized that the hazard estimation is also based on the output of the model simulation in the form of parameter maps such as flood velocity, depth of water, and flood impulse. The pre-requisite for flood hazard is estimated by its frequency analysis or return period calculation [131]. Hydrographs for different return periods are the basis for understanding the hydrologic response of the basin [132].

The following characteristics are important in terms of the physical hazard posed by floods event:

a. The depth of water and its spatial variability;
b. The extent of inundation, and in particular the area that is not normally covered with water;

c. The water velocity and its spatial variability;
d. Duration of flooding;
e. Capacity for erosion and sedimentation (In this research this parameter did not conclude due to lack of data)

The importance of water velocity should not be underestimated, as high velocity water can be extremely dangerous and destructive. In the case of a flood flowing into a reservoir, the flood volume and possibly hydrograph shape should be added to the list of important characteristics. In most cases, however, the flow rate is important because it is used, in conjunction with the topography and condition of the channel/floodplain in determining the water depth, velocity, and area of inundation. Characteristics such as the number of rivers and streams involved in a flood event, total size of the affected area, duration of flooding, and the suddenness of onset are related to the cause of flooding. Usually, these space–time factors are determined primarily by the space–time characteristics of the causative rainstorm and secondarily by watershed characteristics such as area and slope. Because of the seasonality of flood-producing storms or snowmelt, the probability of floods occurring in a given watershed can differ markedly from season to season. On a given river, small floods (with smaller discharges, lower stages, and limited aerial extent) occur more frequently than large floods. Flood-frequency diagrams are used to illustrate the frequency with which floods of different magnitudes occur. The slope of the flood-frequency relation is a measure of the variability of flooding [22].

The development of the flood hazard map, and its subsequent reviews, will be carried out to include as much information to assist future researches. The flood hazard maps in this thesis cover the geographical areas which could be flooded according to the following scenarios:

a. Floods with a low probability, or extreme event scenarios;
b. Floods with a medium and high probability (return period $\leq$100 years);
c. Floods with a high probability (with the assumption of dyke failure).

For each scenario referred the following elements are shown:

a. The flood extent;
b. Water depths or water level;
c. Where appropriate, the flow velocity or the relevant water flow.

Simulation and modeling for flood estimation is a rapidly developing field in hydrology. The flood simulation and model results provide the authorities with relevant information on how the flood is going to behave at the location where people live and how the flood will affect them [133].

2.11 Presentation of Hazard Assessment

In order to have available and more effective tools for providing the people with information, as well as a valuable basis for priority setting and further environmental, technical, financial, and political decisions regarding flood hazard/risk management, it is necessary to establish flood hazard maps. These maps are showing the potential adverse consequences associated with different flood scenarios, including information on potential sources of environmental damages as a consequence of floods [37, 134].

Assessment of flood hazard is extremely important in hydraulic design, river engineering, and land management, e.g., the construction of buildings and residence is often restricted in high flood hazard areas and flood plain. Critical facilities such as hospitals or nuclear power plants should be constructed and located in low-flood-hazard areas or in areas where the flood hazard is essentially zero [135]. For locations where dam failure may occur in case of massive flooding, dam spillways must be fit designed to pass extremely large floods without dam failure occurrence [22].

Maps are the standard format for presenting flood hazards. Areas subject to flooding are indicated on topographic base maps through shading, coloring, or drawing lines around the indicated area. The flood-hazard areas may be divided according to severity (deep or shallow), type (quiet water or high velocity), or frequency of flooding. Different symbols (different types of shading, colors or lines) should be used to clearly indicate the different types of flood-hazard area, and there should be written explanations, either on the map or in an accompanying report, as to the exact meaning of the symbols. The maps will be easier to read if extraneous information is omitted from the base maps. Maps should always have a graphic scale. Numeric scales (e.g., 1:1 000) lose their validity when the map is reduced or enlarged. Ancillary information may accompany the basic maps: flood-frequency diagrams; longitudinal profiles or channel cross-sections showing water level as a function of flood frequency; information on velocity; suddenness of onset; duration of flooding; the expected causes; and season of flooding.

The actual maps can be prepared manually using standard cartographic techniques or with a GIS. The format and scale of a hazard map will depend on the purpose for which it is used, and it may be desirable to have more than one type of map. High-resolution flood maps are necessary to show the exact location of the flood hazard. Such maps may be used by individuals and authorities to direct new construction into relatively safe areas. For purposes of disaster preparedness, planning and relief efforts, it is best to have maps which depict all types of hazards (natural and human induced).

Disaster-planning maps should also show population and employment centers, emergency services and emergency shelters, utilities, locations of hazardous materials, and reliable transportation routes. It is useful to show which bridges and roads are likely to be made impassable by flooding of various magnitudes, and which are likely to be passable under all foreseeable conditions. Even if a disaster-response plan has not been formulated, these maps can be used in the event of a disaster to direct relief to critical areas by the most reliable routes. Photographs are one of the most effective ways of communicating the consequences of a hazard. If photographs that are appropriate to the local nature of the hazard accompany hazard maps, then more people are likely to pay attention to them. Communication of the infrequent and probabilistic nature of the hazard is important, though difficult. This is particularly important in areas protected by levees. Hazard maps should be made widely available in paper format to local communities and authorities. They should be distributed to:

a. Those who may be involved in disaster-relief efforts;
b. The public; and
c. Those who may be in a position to implement mitigation measures.

For planning and evacuation procedures, the demand for flood information and digital maps has been increased. Ideally, the key organizations involved in disaster-relief efforts will have the maps displayed permanently on a wall, and will have studied the maps and instituted disaster planning. Ideally, the public, community leaders, and government bodies will also study the maps and appreciate that prevention is worthwhile, and implement appropriate mitigation measures. Also, near full-scale disaster exercises may be conducted periodically to maintain the readiness of disaster relief and management organizations, and to keep the public aware of the potential hazard [22].

2.12 Chapter Summary

This chapter gave a comparative overview of the major challenges faced when dealing with hydrodynamic simulation and flood hazard. In the first part, definition, source, and implication of digital elevation model were explained. DEM is usually produced form sampled or observed data. Spurious sinks or local depressions in DEMs are frequently encountered and are a significant source of problems in hydrological applications. In this case, application of interpolation techniques seems to be necessary to correct DEMs. Therefore, in this part, the attempt was introducing different interpolation techniques drainage network estimation coupled with advantages and disadvantages of these methods and their application in different research fields. In the next part, flood hazard, concepts, definition, types, and causes were defined. Then, the focus was on providing a background to climate change and land use change as the most important triggering factors which affects on flood events. This background was overviewed and estimated from global to local (Barcelonnette area) based on different scientific researches. According to previous researches, there have been adverse flood hazard changes due to climate change. Many investigators believe that climate change is expected to have substantial impacts on hydrology on global, regional and local scale. According to IPCC, increasing trend in temperature was distinguished about +0.90 °C in Europe.

In some other researches negative trend in annual precipitation was found in the east of Europe. IPCC [38–40] also reported that there was a 10–40 % increasing trend in precipitation in the t century in northern Europe but, on the other hand, there was up to a 20 % decreasing trend in the southern part of Europe. Apart from climatic factors, another significant reason, for increasing flood hazards can be related to non-climatic anthropogenic factors: Changes in socioeconomic systems include land-use changes such as deforestation, urbanization, elimination of floodplains area, as well as river regularizations which leads to reducing of infiltration capacity and increasing of runoff coefficient. In recent decades, the scientific investigation shows that a lot of inundation has occurred in Europe causing loss of human lives and financial damages which have been aggravated, in several cases, by the intense urbanization of flood-prone areas.

For Barcelonnette area, the effect of climate change on landslide and slop stability using downscaling methods was investigated by some researchers. The general results were higher temperatures in summer, more rainy winters and spring, drier summers with decreasing precipitation, and a decrease in soil water content. In terms of land-use change, many authors have addressed in their investigations to deforestation in the floodplains of the rivers in south-eastern France in the late eighteenth and nineteenth centuries ([122]. In contrast with the vegetation explosion of the early twentieth century, changes were observed over shorter time periods and in smaller areas, in the riparian forest active channel contacts. Bravard [123] realized that anthropogenic factors played a major part in initiating active channel restriction at the turn of the century, with climate change as a secondary factor in Barcelonnette area.

In the next chapter, the methodology applied in this research will be explained in details.

References

1. Vaze J, Teng J, Spencer G (2010) Impact of DEM accuracy and resolution on topographic indices. Environ Model Softw 25:1086–1098
2. Hutchinson MF, Gallant JC (2000) Digital elevation models and representation of terrain shape. In: Wilson JP, Gallant JC (eds) Terrain analysis. Wiley, New York, pp 29–50
3. Hutchinson M, Stein J, Stein J (2008) User's guide, GEODATA 9 second "DEM and D8", digital elevation model version 3 and flow direction grid, fenner school of environment and society. Australian National University (ANU) and Hamish Anderon and Phil Tickle, geosciences Australia
4. Teng J, Vaze J, Tuteja NK, Gallant J (2008) A GIS based tool for spatial and distributed hydrological modelling: CLASS spatial analyst. Trans GIS 12(2):209–225
5. Burrough PA, McDonnell RA (1998) Principals of geographical information systems. Oxford University Press, New York, p 333
6. Wood J (1996) The geomorphological characterization of digital elevation models. Ph.D. Dissertation, Department of Geography, University of Leicester, Leicester, UK
7. Olivera F, Furnans D, Maidment D, Djokic Z (2002) Drainage system, Arc hydro: GIS for water resources. In: Maidment DR (ed) ESRI Press, Redlands, p 203

8. Wechsler S (1999) Results of the DEM user survey. Available online at: http://web.syr.edu/~sperlit/survey. Verified 28 Nov 2011
9. Harding DJ, Bufton JL, Frawley J (1994) Satellite laser altimetry of terrestrial topography: vertical accuracy as a function of surface slope, roughness and cloud cover. IEEE Trans Geosci Remote Sens 32:329–339
10. Burrough PA (1986) Principles of geographical information systems for land resources assessment, vol 12. Clarendon Press, New York
11. Hutchinson MF, Dowling TI (1991) A continental hydrological assessment of a new grid-based digital elevation model of Australia. Hydrol Process 5:45–58
12. ANUDEM User's Manual (2011) Fenner school of environment and society. ANU College of Medicine, Biology and Environment. http://fennerschool.anu.edu.au/research/publications/software-datasets/anudem. Verified 28 Nov 2011
13. Jenson SK, Domingue JO (1988) Extracting topographic structure from digital elevation data for geographic information system analysis. Photogram Eng Remote Sens 54:1593–1600
14. Taylor J (1997) An introduction to error analysis: the study of uncertainties in physical measurements. University Science Books, Sausalito, p 327
15. Podobnikar T (2006) DEM from various data sources and geomorphic details enhancement, 5t ICA mountain cartography workshop. Bohinj, 31 Mar 2006
16. Fürst J (2004) Tutorial: interpolation of hydrological variables. University of Natural Resources and Life Sciences, Vienna
17. Smith MJ, Goodchild MF, Longley PA (2009) Geospatial analysis, a comprehensive guide to principles, techniques and software tools, 3rd edn., Issue version: 3.1 2—Published by Matador (an imprint of Troubador Publishing Ltd) on behalf of The Winchelsea Press
18. Akkala A, Devabhaktuni V, Kumar A (2010) Interpolation techniques and associated software for environmental data. Environ Prog Sustain Energ 29:134–141
19. ArcGIS 9.3-online help (2011) Available online at: http://webhelp.esri.com. Verified 28 Nov 2011
20. Wilson JP, Gallant JC (2000) Differences in topographic characteristics computed from 100- and 1000-m resolution digital elevation model data. Hydrol Process 14:987–1002
21. Wilson JP, Gallant JC (2000) Digital terrain analysis. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and application. Wiley, New York, pp 1–27
22. IAEA/WMO (2006) Global Network of Isotopes in Precipitation. The GNIP Database. (http://isohis.iaea.org), accessed August 2010
23. Wise SM (1998) The effect of GIS interpolation errors on the use of digital elevation models in geomorphology. In: Lowe SN, Richards KS, Chandler JH (eds) Landform monitoring, modelling and analysis. Wiley, New York, pp 139–164
24. Kundzewicz Z (2003) Extreme precipitation and floods in the changing world. IAHS-AISH Publ 281:32–39
25. Directive 2007/60/EC of the European parliament and of the council of 23 Oct 2007 on the assessment and management of flood risks text with EEA relevance. Official Journal of the European Union, L 288, pp 0027–0034
26. UN-ISDR (2004) International Strategy for Disaster Reduction, Available online at: http://www.unisdr.org (Verified 28 Nov 2011)
27. Aysan YF (1993) Vulnerability assessment. In: Merriman PA, Browitt CWA (eds) Natural disasters: protecting vulnerable communities. Thomas Telford, London, pp 1–14
28. Davis L (1992) Natural disasters: from the black plague to the eruption of Mt. Pinatubo, Facts on File, 321:1976
29. Wasseff AM (1993) relative impact on human life of various types of natural disaster: an interpretation of data for the period 1947–1991. In natural disasters: protecting vulnerable communities. Thomas Telford, London, pp 15–24
30. Wijkman A, Timberlake L (1984) Natural disasters: acts of god or acts of man?. International Institute for Environment and Development press, Washington, p 126

31. Yen C-L, Yen BC (1996) A study on effectiveness of flood mitigation measures. In: Maxwell WHC, Preul HC, Stout GE (eds) Proceedings, Rivertech'96, 1st international conference on new/emerging concepts for rivers, International Water Resources Association, Albuquerque, NM, pp 555–562
32. Munich Reinsurance (1997) Topics: annual review of natural catastrophes 1996, Munich Re 2005. p 16
33. Kundzewicz ZW, Jun X (2004) Towards an improved flood preparedness system in China Hydrol Sci J 49(6):941–944
34. Schultz B (2006) Floods management under rapid urbanization and industrialization in flood-prone areas: a need for serious consideration. Irrig Drainage 55:3–8
35. World Meteorological Organization (WMO) (1981a) Flash flood forecasting, operational hydrology report no. 18, (WMO-No. 577), Geneva, Switzerland, p 47
36. World Meteorological Organization (WMO) (1994) Guide to hydrological practices, (WMO-No. 168), vol 2, 5th edn. Geneva, Switzerland, p 765
37. COM (2004) 472 final, Brussels, 12 July 2004, Commission of the European communities, Communication from the commission to the council, The European parliament, The European economic and social committee and the committee of the regions, Flood risk management, Flood prevention, protection and mitigation
38. Intergovernmental Panel on Climate Change (IPCC) (2007a) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment, Report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York, p 996
39. Intergovernmental Panel on Climate Change (IPCC) (2007b) Summary for policymakers. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability, contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, pp 7–22
40. Intergovernmental Panel on Climate Change (IPCC) (2007c) Climate change 2007: synthesis report, contribution of working group to the fourth assessment report of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge
41. United States Search and Rescue Task Force (2011) Floods and flash floods, available online at: http://www.ussartf.org/flooding.htm. Verified 28 Nov 2011
42. Kundzewicz ZW, Jun X (2004) Towards an improved flood preparedness system in China. Hydrol Sci J 49(6):941–944
43. Andréasson J, Bergström S, Carlsson B, Graham L, Lindström G (2004) Hydrological change—climate change impact simulations for Sweden. Ambio 33:228–234
44. Lotsari E, Veijalainen N, Alho P, Käyhkö J (2010) Impact of climate change on future discharges and flow characteristics of the Tana river, Sub-Arctic Northern Fennoscandia. Geografiska Annaler: Ser A, Phys Geogr 92:263–284
45. Kjellström E, Bärring L, Gollvik S, Hansson U, Jones C, Samuelsson P, Rummukainen M, Ullerstig A, Willén U, Wyser K (2005) A 140 year simulation of European climate with the new version of the Ross by centre regional atmospheric climate model (RCA3). Reports meteorology and climatology, 108, SMHI, SE-60176 Norrköping, Sweden, p 54
46. Beldring S, Engen-Skaugen T, Førland EJ, Roald LA (2008) Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological station sites. Tellus A 60:439–450
47. Intergovernmental Panel on Climate Change (IPCC) (1995) Climate changes 1995: contribution of working group I to the second report of the intergovernmental panel on climate change. pp 141–193
48. Lettenmaier DP, Wood EF, Wallis JR (1994) Hydro-climatological trends in the continental United States (1948–1988). J Clim 7:586–607

49. Plummer N, Salinger MJ, Nicholls N, Suppiah R, Hennessy KJ, Leighton RM, Trewin B, Page CM, Lough JM (1999) Changes in climate extremes over the Australian region and New Zealand during the twentieth century. Clim Change 42:183–202
50. Suppiah R, Hennessy K (1998) Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910–1990. Int J Climatol 10:1141–1164
51. Viglizzo EF, Roberto ZE, Filippin MC, Pordomingo AJ (1995) Climate variability and agroecological change in the central Pampas of Argentina. Agric Ecosyst Environ 55:7–16
52. Gruza G, Rankova E, Razuvaev V, Bulygina O (1999) Indicators of climate change for the Russian federation. Clim Change 42:219–242
53. Zhai P, Sun A, Ren F, Liu X, Gao B, Zhang Q (1999) Changes of climate extremes in China. Clim Change 42:203–218
54. Türke SM (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. Int J Climatol 16:1057–1076
55. Hess TM, Stephens W, Maryah UM (1995) Rainfall trends in the north east arid zone of Nigeria 1961–1990. Agric For Meteorol 74:87–97
56. Mason SJ (1996) Climatic change over the lowveld of South Africa. Clim Change 32:35–54
57. Heino R, Forland E, Tuomenvirta H, Alexandersson H, Beniston M, Pfister C, Rebetez M, Rosenhagen G, Jones PD, Horton EB, Folland CK, Hulme M, Parker DE, Basnett TA (1999) The use of indices to identify changes in climatic extremes. Clim Change 42:131–149
58. Bootsma A (1994) Long-term (100 years) climate trends for agriculture at selected locations in Canada. Clim Change 26:65–88
59. Smit B, Ludlow L, Brklacich M (1988) Implications of a global climatic warming for agriculture: a review and appraisal. J Environ Q 17:519–527
60. Zhang X, Vincent LA, Hogg WD, Niitsoo A (2000) Temperature and precipitation trends in Canada during the 20th century. Atmos Ocean 38:395–429
61. Gonzalez Hidalgo JC, De Luis M, Raventos J, Sanchez JR (2003) Daily rainfall trend in the valencia region of Spain. Theoret Appl Climatol 75:117–130
62. Gong DY, Shi PJ, Wang JA (2004) Daily precipitation changes in the semi-arid region over northern China. J Arid Environ 59:771–784
63. Del Rio S, Penas A, Fraile R (2005) Analysis of recent climatic variations in castle and leon (Spain). Atmos Res 73:69–85
64. Partal T, Kahya E (2006) Trend analysis in Turkesh precipitation data. Hydrol Process 20:2011–2026
65. Balling RC, Skindlow JA, Philips DA (1990) The impacts of increasing summer mean temperatures on extreme maximum and minimum temperatures in Phoenix, Arizona. J Clim 3:1491–1494
66. Esterling DR, Evans LG, Groisman PY, Karl TR, Kunkel KE, Ambenje P (2000) Observed variability and trends in extreme climate events: a brief review. Bull Am Meteorol Soc 3:417–425
67. Esterling DR, Horton B (1997) Maximum and minimum temperature trends for the globe. Science 227:364–367
68. Nicholls N, Gruza GV, Jouzel J, Karl TR, Ogallo LA, Parker DE (1996) Observed climate variability and change. In: Houghton JT, Filho LGM, Callander BA, Harris N, Kattenberg A, Maskell K (eds) Climate change 1995: the science of climate change. Cambridge University Press, Cambridge, pp 133–192
69. Unkasevic D, Vujovic D, Tosic I (2005) Trends in extreme summer temperatures at Belgrade. Theoret Appl Climatol 82:199–205
70. Mearns LO, Katz RW, Schneider SH (1984) Extreme high temperature events: changes in theri probabilities with changes in mean temperature. J Climatol Appl Meteorol 23:1601–1613
71. Hansen J, Fung I, Lacis A, Rind D, Lebedeff S, Ruedy R, Russel G, Stone P (1988) Global climate change as forecast by goddard institute for space studies three dimensional model. J Geophys Res 93:9341–9354

72. Ghosh S (2011) Impact of climate change and land use change on the flood vulnerability of Brahmaputra basin. Geospatial world forum, 18–21 Jan 2011, Hydarabad, India
73. Jones PD, Moberg A (2003) Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001. J Clim 16:206–223
74. Douville H, Chauvin F, Planton S, Royer J-F, Salas-Mélia D, Tyteca S (2002) Sensitivity of the hydrological cycle to increasing amounts of greenhouse gases and aerosols. Clim Dyn 20:45–68
75. Intergovernmental Panel on Climate Change (IPCC) (2001a) In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001: impacts, adaptation and vulnerability, contribution of the working group II to the third assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, UK, p 1032
76. McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (2001): Climate change 2001: Impacts, adaptation, and vulnerability. Cambridge University Press, p 1032
77. European Environment Agency (EEA) (2008) River floods (CLIM 017)—assessment published Sep 2008. Available online at: http://www.eea.europa.eu/data-and-maps/indicators/river-floods/river-floods-assessment-published-sep-2008. Verified 28 Nov 2011
78. Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hansen CD (eds) (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
79. Brázdil R, Kotyza O, Dobrovolný P (2006) July 1432 and August 2002–two millennial floods in Bohemia? Hydrol Sci J 51(5):848–863
80. Cyberski J, Grześ M, Gutry-Korycka M, Nachlik E, Kundzewicz Z (2006) History of floods on the river Vistula. Hydrol Sci J 51(5):799–817
81. Kundzewicz ZW (2008) Flood risk and vulnerability in the changing climate, annals of Warsaw university of life sciences—SGGW. Land Reclam 39:21–30
82. Mudelsee M, Börngen M, Tetzlaff G, Grünewald U (2003) No upward trends in the occurence of extreme floods in central Europe. Nature 425:166–169
83. Palmer TN, Räisänen J (2002) Quantifying the risk of extreme seasonal precipitation in a changing climate. Nature 415:512–514
84. Kay AL, Jones RG, Reynard NS (2006) RCM rainfall for UK flood frequency estimation. II. Climate change results. J Hydrol 318:163–172
85. Graham LP, Andre′asson J, Carlsson B (2007) Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods—a case study on the Lule river basin. Clim Change 81:293–307
86. Booij MJ (2005) Impact of climate change on river flooding assessed with different spatial model resolutions. J Hydrol 303:176–198
87. Shabalova M, Van Deursen W, Buishand T (2003) Assessing future discharge of the river Rhine using RCM integrations and a hydrological model. Clim Res 23:233–246
88. Lehner B, Doll P, Alcamo J, Henrichs T, Kaspar F (2006) Estimating the impact of global change on flood and drought risks in Europe: a continental integrated analysis. Clim Change 75:273–299
89. Jain S, Lall U (2000) Magnitude and timing of annual maximum floods: trends and large scale climatic associations for the Blacksmith Fork River, Utah. Water Resour Res 36:3641–3651
90. Sharma KP, Moore B, Vorosmarty CJ (2000) Anthropogenic, climatic and hydrological trend in the Kosi basin. Himalaya, Clim Change 47:141–165
91. Kothyari UC, Singh VP (1996) Rainfall and temperature trends in India. Hydrol Process 10:357–372
92. Meher-Homji VM (1991) Probable impact of deforestation on hydrological processes. Clim Change 19:163–173

93. Malet J-P, Maquaire O, Remaitre A, Thiery Y, Peyron M, Waeckel C (2010) Landslide hazard and risk assessment in the Barcelonnette basin, Mountain risks, research training networks, Causeries de L'e'te'—Barcelonnette, 23 June 2010
94. Buma JT, Dehn M (1996) Development of a method for predicting the impact of climate change on slope stability, Workshop on landslide and flash flood, Barcelonnette—Vaison la Romaine 30 Sept–3 Oct 1996
95. Buma JT, Dehn M (2000) Impact of climate change on landslide in South East France, simulated using different GCM scenarios and downscaling methods for local precipitation. Clim Res 15:69–81
96. Kundzewicz ZW, Schellnhuber H-J (2004) Floods in the IPCC TAR perspective. Nat Hazards 31:111–128
97. Schumann G, Hostache R, Puech C, Hoffmann L, Matgen P, Pappenberger F, Pfister L (2007) High-resolution 3-D flood information from radar imagery for flood hazard management. IEEE Trans Geosci Remote Sens 45(6):1715–1725
98. Van Stokkom HTC, Smits AJM, Leuven RSEW (2005) Flood defence in the Netherlands: a new era, a new approach. Water Int 30:76–87
99. Yuan F, Sawaya K, Loeffelholz B, Bauer M (2005) Land cover classification and change analysis of the twin cities (Minnesota) metropolitan area by multitemporal landsat remote sensing. Remote Sens Environ 98:317–328
100. Brockerhof M (2000) An urbanizing world. Population Bull 55(3):1–44
101. Orr HG, Carling PA (2006) Hydro-climatic and land use changes in the river Lune catchment, North West England, implications for catchment management. River Res Appl 22(2):239–255
102. Rosso R, Rulli MC (2002). An integrated simulation method for flash-flood risk assessment: 2. Effects of changes in land-use under a historical perspective. Hydrol Earth Syst Sci 6(2):285–294
103. Tollan A (2002) Land-use change and floods: what do we need most, research or management? Water Sci Technol 45(8):183–190
104. Patric JH, Reinhart GK (1971) Hydrologic effects of deforesting two mountain watersheds in west Virginia. Water Resour Res 7(5):1182–1188
105. Bannister EN (1979) Impact of road networks on south eastern Michigan lakeshore drainage. Water Resour 15:1515–1520
106. Costa MH, Botta A, Cardille JA (2003) Effects of large-scale changes in land cover on the discharge of the Tocantins River. Southeast Amazonia, J Hydrol 283:206–217
107. Brath A, Montanari A (2000) Effects of the spatial variability of soil infiltration capacity in distributed rainfall runoff modelling. Hydrol Process 14:2779–2794
108. Naef F, Scherrer S, Weiler M (2002) A process based assessment of the potential to reduce flood runoff by land use change. J Hydrol 267(1–2):74–79
109. Bosch JM, Hewlett JD (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J Hydrol 55:3–23
110. Beighley RE, Moglen GE (2002) Trend assessment in rainfall runoff behaviour in urbanizing watersheds. J Hydrol Eng 7:27–34
111. Luft G, Morgenschweis G, Vogelbacher A (1982) The effects of large-scale terracing on hydrological processes, Presentation of first results of a study comparing two small experimental basins on the Kaiserstuhl-Mountain. Proceedings of symposium on hydrological research basins, Sonderheft Landeshydrologie, Bern, pp 543–553
112. Ranzi R, Bochicchio M, Bacchi B (2002) Effects on floods of recent afforestation and urbanisation in the Mella River (Italian Alps). Hydrol Earth Syst Sci 6:239–253
113. Peck AJ, Williamson DR (1987) Effects of forest clearing on groundwater. J Hydrol 94:47–65
114. Armando B, Monanari A, Moretti G (2006) Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). J Hydrol 324:141–153
115. Sullivan A, Ternan JL, Williams AG (2004) Land use change and hydrological response in the camel catchment. Cornwall Appl Geogr 24(2):119–137

116. De Roo APJ, Schmuck G, Perdigao V, Thielen J (2003) The influence of historic land use changes and future planned land use scenarios on floods in the oder catchment. Phys Chem Earth (B) 28(33–36):1291–1300
117. Reynard NS, Prudhomme C, Crooks SM (2001) The flood characteristics of large UK rivers: potential effects of changing climate and land use. Clim Change 48:343–359
118. McMillan HK (2002) The estimation of discharges in ungauged sub-catchments of the River Eden in Cumbria, Unpublished Master Thesis, Lancaster University
119. Bultot F, Dupriez GL, Gellens D (1990) Simulation of land-use changes and impacts on the water balance, a case study for Belgium. J Hydrol 114:327–348
120. Eiker E, Davis DW, Goldman DM (2000) Application of risk-based analysis to planning reservoir and levee flood damage reduction systems. Us Army Corps of Engineers Hydrologic Engineering Center (HEC), USA, pp 1–30
121. Remaitre A, Malet J-P (2010) The effectiveness of torrent check dams to control channel instability: example of debris-flow events in clay shales. In: Garcia CC, Lenzi MA (eds) Check dams, morphological adjustments and erosion control in torrential streams. Nova Science Publishers Inc., New York, pp 211–237
122. Bravard J-P (1986) Le Rh6ne, du Leman a Lyon. p 450, La Manufacture, Lyon. Peiry 1988 (In French)
123. Bravard J-P (1989) La metamorphose des rivieres des Alpes francaises a la fin du moyen-age et a l'epoque moderne. Bull Soc Geog Liege 25:145–157 (In French)
124. Schumm SA (1977) The fluvial system. Wiley, New York 338
125. Hey RD, Thorne CR (1986) Stable channels with mobile gravel-bed rivers. J Hydraul Eng 8:671–689
126. Gonde R (1981) Les amenagements du lit de la Durance et l'evolution du milieu naturel, p 65. Report of Ministere de l'Environnement et du Cadre de Vie, Paris (In French)
127. Piegay H, Bravard JP, Dupont P (1994) Les ripisylves et les crues dans la France du sud-est: de l'histoire a la gestion contemporaine. 23emes Journees de I'Hydraulique: Crues et inondations (ed. by Societ6 Hydrotechnique de France), pp 277–289. Nimes, France (In French)
128. Penning-Rowsell EC, Johnson C, Tunstall S, Tapsell S, Morris J, Chatterton J, Green C (2005) The benefits of flood and coastal risk management: a manual of assessment techniques. Middlesex University Press, London
129. Bhattacharya N (2010) Flood risk assessment in Barcelonnette, France, M.Sc. thesis, International Institute for Geo-information Science and Earth Observation (ITC), Twente University, Enschede, The Netherlands
130. Alkema D (2007) Simulating floods, on the application of a 2D-hydraulic model for flood hazard and risk assessment, Ph.D. Dissertation, International Institute for Geo-information Science and Earth Observation (ITC), Twente University, Enschede, The Netherlands. ISBN 978 90 6164 263 3
131. Apel H, Thieken A, Merz B, Blöschl G (2006) A probabilistic modelling system for assessing flood risks. Nat Hazards 38:79–100
132. Jain V, Sinha R (2006) Evaluation of geomorphic control on flood hazard through geomorphic instantaneous unit hydrograph. Current science association
133. Boughton WC, Droop O (2003) Continuous simulation for design flood estimation—a review. Environ Model Softw 18(4):309–318
134. Plate EJ (2007) Flood risk management for setting priorities in decision making, Springer. Vasiliev OF, van Gelder PHAJM, Plate EJ, Bolgov MV (eds) Extreme hydrological events: new concepts for security. pp 21–44
135. World Meteorological Organization (WMO) (1981c) Meteorological and hydrological aspects of siting and operation of nuclear power plants, vol II Hydrological aspects, technical note no. 170, (WMONo. 550), Geneva, Switzerland, p 125
136. Klein Tank AMG, Wijngaard JB, Konnen GP, Bohm R, Demaree G, Gocheva A, Mileta M, Pashiardis S, Hejkrlik L, Kern-Hansen C, Heino R, Bessemoulin P, Muller-Westermeier G,

Tzanakou M, Szalai S, Palsdottir T, Fitzgerald D, Rubin S, Capaldo M, Maugeri M, Leitass A, Bukantis A, Aberfeld R, VanEngelen AFV, Forland E, Mietus M, Coelho F, Mares C, Razuvaev V, Nieplova E, Cegnar T, López JA, Dahlstrom B, Moberg A, Kirchhofer W, Ceylan A, Pachaliuk O, Alexander LV, Petrovic P (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European climate assessment. Int J Climatol 22:1441–1453
137. Klein Tank AMG, Können GP (2003) Trends in indices of daily temperature and precipitation extremes in Europe. J Clim 16:3665–3680
138. Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Tankand AMGK, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19:193–212
139. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin D, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vázquez Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:1–22
140. Norrant C, Douguédroit A (2006) Monthly and daily precipitation trends in the mediterranean. Theor Appl Climatol 83:89–106
141. Piegay H, Salvador P-G (1997) Contemporary floodplain forest evolution along the middle Ubaye river. Southern Alps, France, Global Ecology and Biogeography Letters 6:397–406
142. Demontzey P (1882) Traite pratique de reboisement et du gazonnement des montagnes. J. Rothschild, Paris (In French), p 528
143. Lecarpentier C (1963) La crue de Juin 1957 en Ubaye et ses conséquences morphodynamiques. Ph.D. Dissertation, Faculty of Geography, Strasbourg University, p 319 (In French)
144. Sclafert T (1933) A propos du d6boisement des Alpes du Sud. Ann Geogr 42:266–277 (In French)
145. Salvador PG (1991) Le theme de la metamorphosefluviale dans lesplaines alluviales du Rh6ne et de l'Isere (Bassin de Malville et Ombilic de Moirans, Bas-Dauphine), p 529. Th&se de geographie, Universite Lyon III, Lyon (In French)

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